Advanced Precipitation Radar Antenna (APRA)

Y. Rahmat-Samii*, J. Huang, B. Lopez, M. Lou,
E. Im, S. L. Durden, K. Bahadori*

* University of California Los Angeles

Jet Propulsion Laboratory

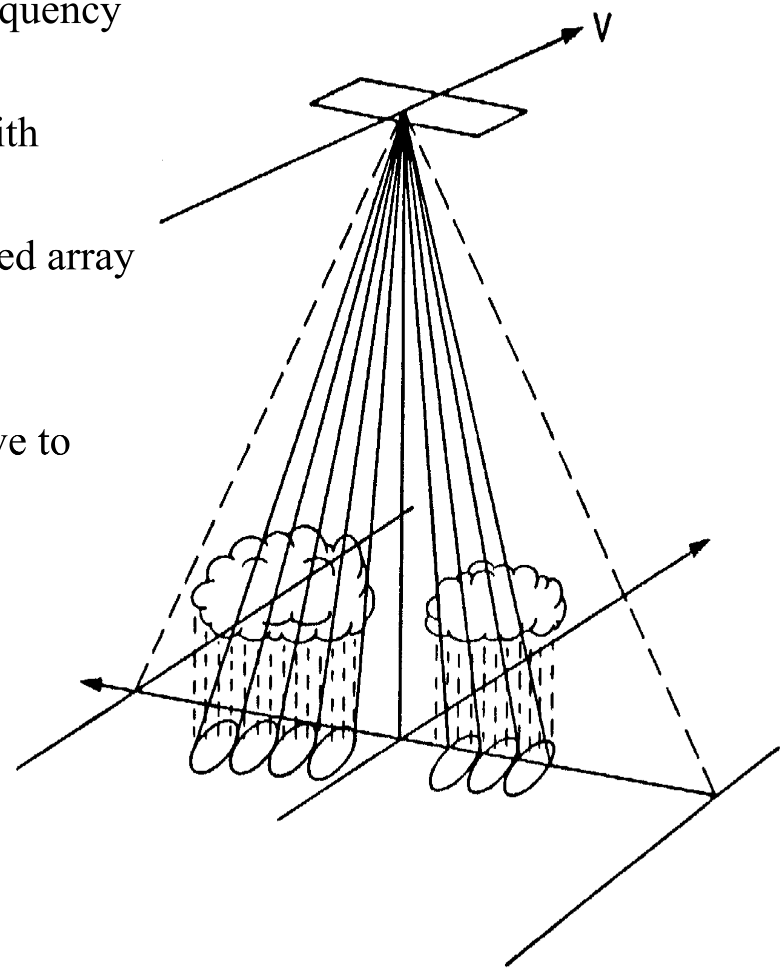
Earth Science Technology Conference
June 24-26, 2003

Background

- Several years ago we developed a conceptual design of a Second Generation Precipitation Radar (PR-2).
- That work was motivated by the success of the Tropical Rainfall Measuring Mission (TRMM); its precipitation radar (the first generation of spaceborne precipitation radar) has performed exceptionally well, providing what is now a science record of 5.5 years.
- PR-2 was designed to provide several key improvements relative to the TRMM radar:
  - Dual-frequency improves rain measurement accuracy
  - Large antenna improves horizontal resolution and reduces beam-filling bias
  - Large antenna reduces surface clutter
  - Large antenna improves Doppler velocity accuracy
  - Wide-swath scanning antenna improves sampling frequency (reduces revisit time)
  - Digital pulse compression enhances sensitivity and resolution
  - Low mass antenna and compact RF electronics for lower-mass instrument
- The PR-2 RF and digital electronics, including real-time pulse compression, was demonstrated in an airborne PR-2 simulator
  - Acquired data in hurricanes (2001) and winter storms (2003)
- The goal of the work reported here is to demonstrate the deployable antenna design
  - Develop half-scale antenna prototype and test

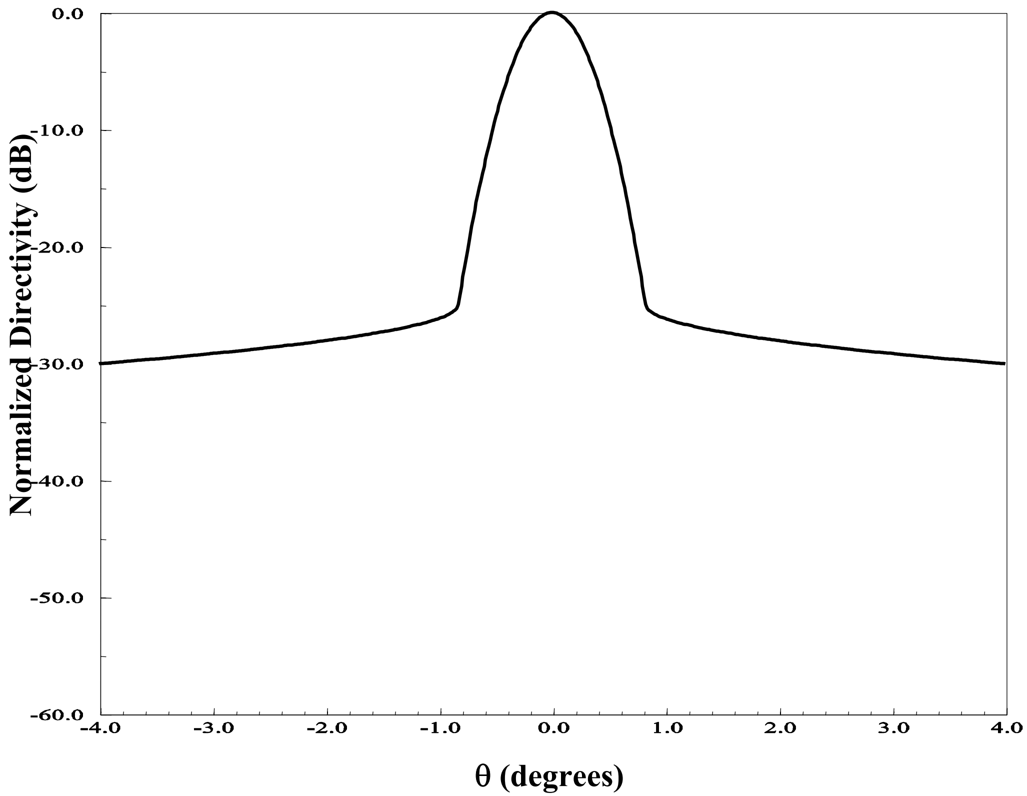
2nd-Generation Precipitation Radar (PR-2) Concept

- 14 GHz (Ku-band) and 35 GHz (Ka-band) dual-frequency radar
- Lightweight, deployable 5.3 m antenna reflector with matched beams:
  - Parabolic cylindrical reflector with linear feed array for cross-track scanning
  - Offset feed for reduced blockage
  - Improved cross-polarization isolation relative to parabolic reflector
- Horizontal resolution:
  - 2 km @ h=400 km
- Wide-swath coverage using adaptive scanning
  - ± 37˚scan, 600 km swath at h=400 km
- Doppler measurements if rain detected at nadir
- Simultaneous HH and HV polarization
- On-board, real-time pulse compression
  - 250 m vertical resolution
- On-board processing: Doppler, pulse averaging



Specifications for Full-Size Antenna

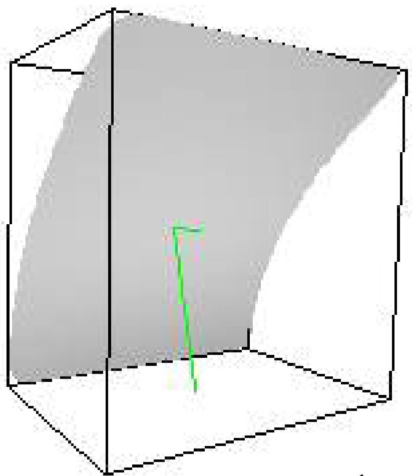
Desired Pattern Envelop

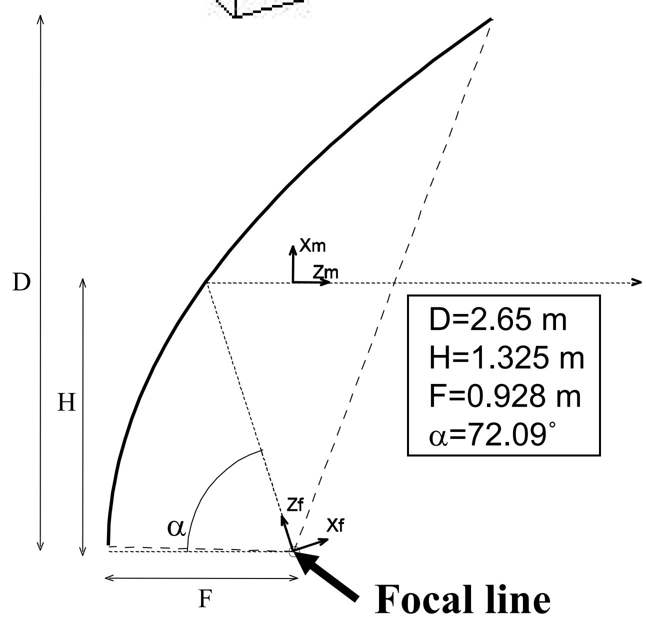


Operating frequency	14/35 GHz
Antenna diameter	5.3m
Antenna gain	50 dBi
Side lobe level	30 dB
Polarization isolation	25 dB
Polarization	HH, HV
Array type	active

To demonstrate the functionality of the proposed 5.3-m antenna/feed design, the 2.65-m scaled breadboard is designed and evaluated in this program.

Reflector Antenna Geometry: 2.65 m Scaled Model





General Parameters of the Antenna

• Diameter	2.65 m
• Offset height	1.325m
• Focal length	0.928m
• F/D	0.35
• Superquadric index	10
• Angle subtended to the center of the projected aperture (deg.)	72.09
• Scan angle	0 & 30˚
• Array type	passive

The objectives are:

(i) the optimal design of the antenna configuration,

(ii) feed array topology selection

(iii) mechanical design for deployment

(iv) characterization of the overall antenna performance at Ku and Ka-band frequencies, H and V pol, 0^o and 30^o scan angles

Optimal Array Design

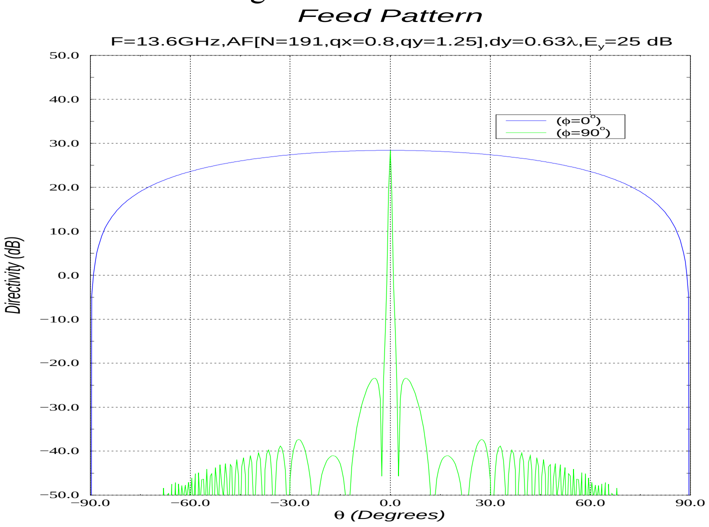
- To fulfill side lobe specification, a Cos ^{2} distribution is used.
- Pedestal heights are:
  - 25 dB at Ku-band
  - 22 dB at Ka-band
- The length of array is scaled for Ka-band by the frequency ratio (14/35).
- At Ku-band, the array feed length is 2.65 m and the number of elements are

($2.65/0.63\lambda_u = 191$).

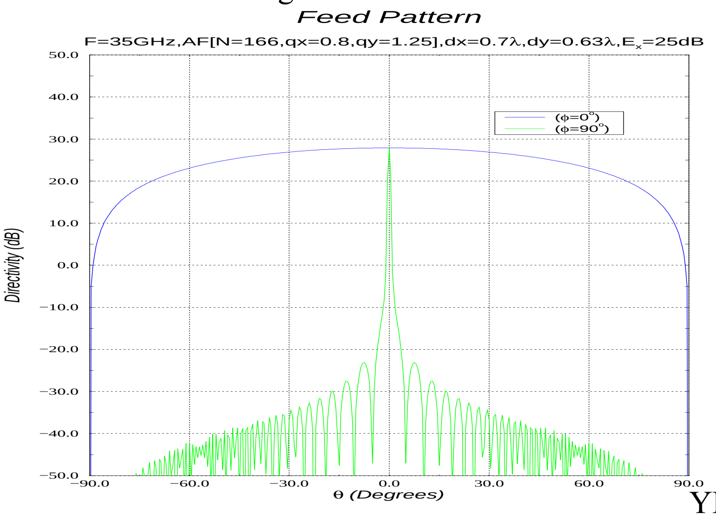
- At Ka-Band, the array feed length is 0.9 m and the number of elements are

($0.9/0.63\lambda_a = 166$).

Far-field pattern of the one row of the feed
Pedestal height of 25 dB at Ku Band



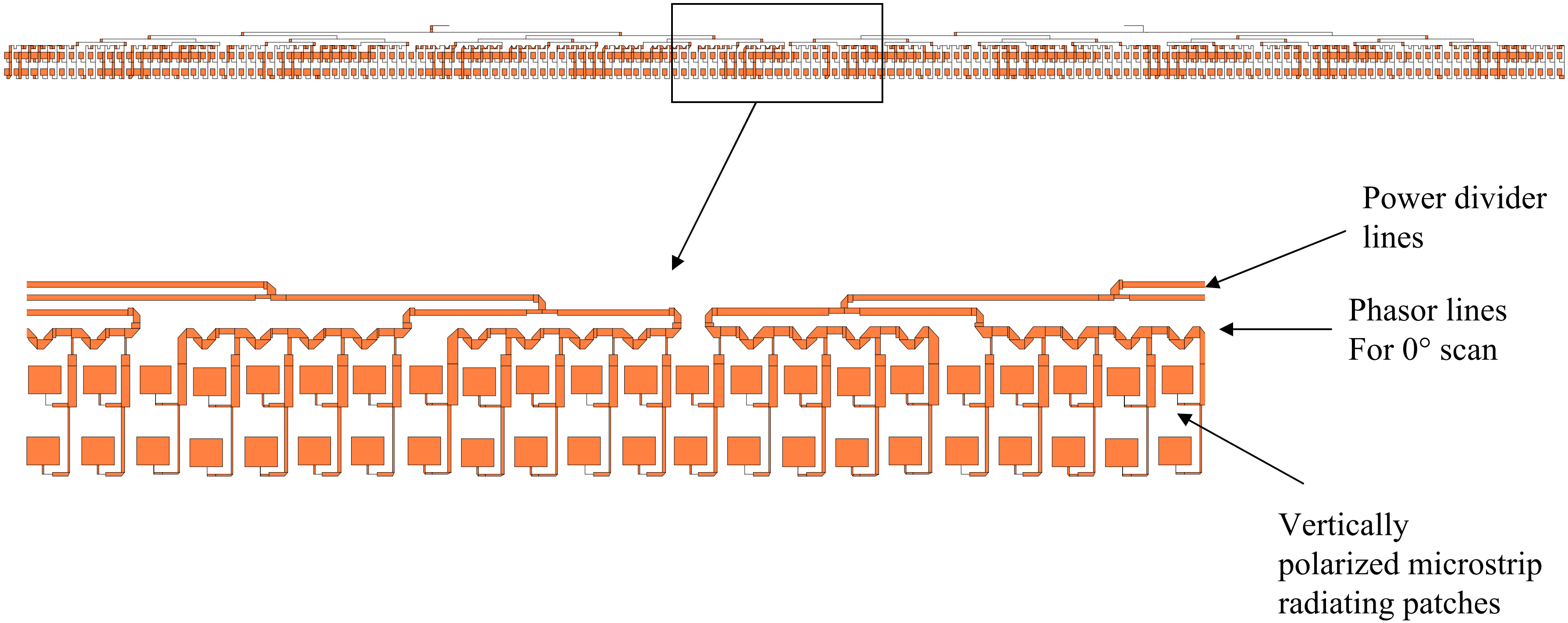
Far-field pattern of the one row of the feed
Pedestal height of 22 dB at Ka Band



Representative Ku-band Array Design

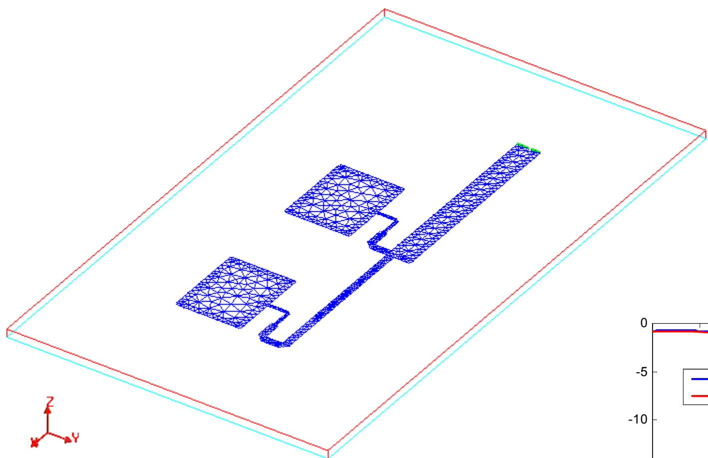
14 GHz feed array with V-pol and 0° scan:

- Each array has 2 x 166 microstrip patch elements
- Size = 2.4m x 6cm
- Substrate thickness = 0.8mm

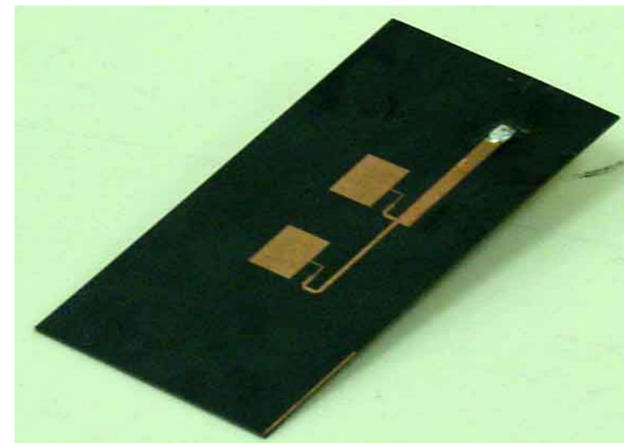


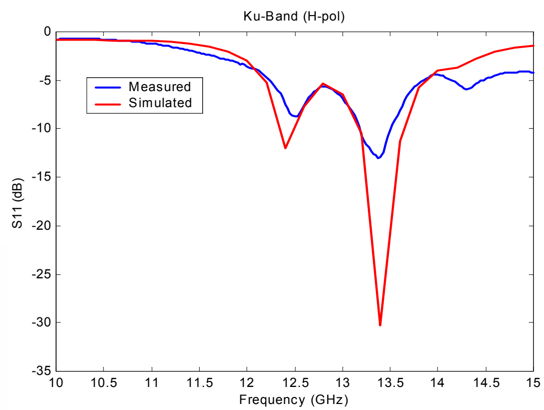
Ku-Band Subarray (V-pol) Simulation & Measurement Results

Subarray Mesh grid Schematic

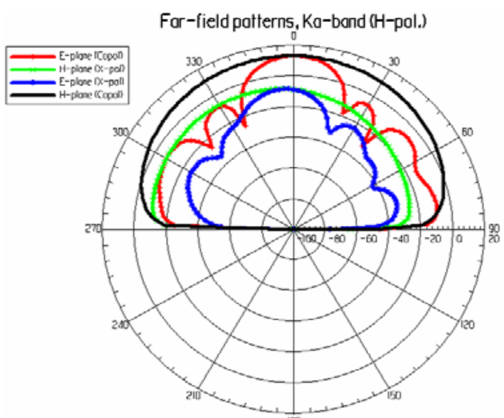


Fabricated Ku-band array

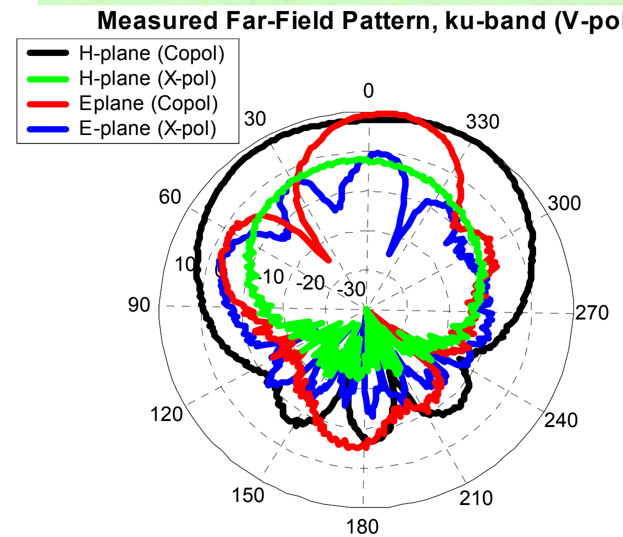




Return loss in dB



Simulated far-field patterns



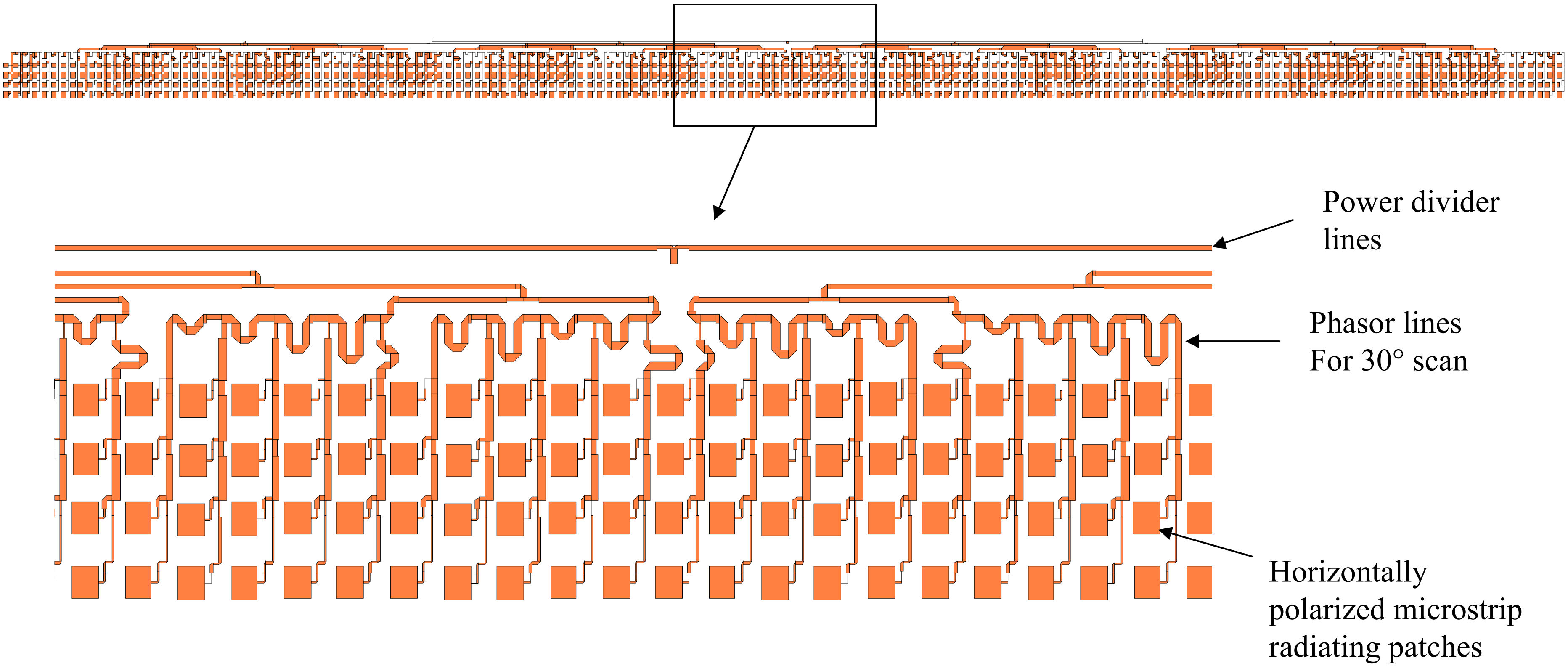
Measured far-field patterns

Ku-band Feed Array

Representative Ka-band Array Design

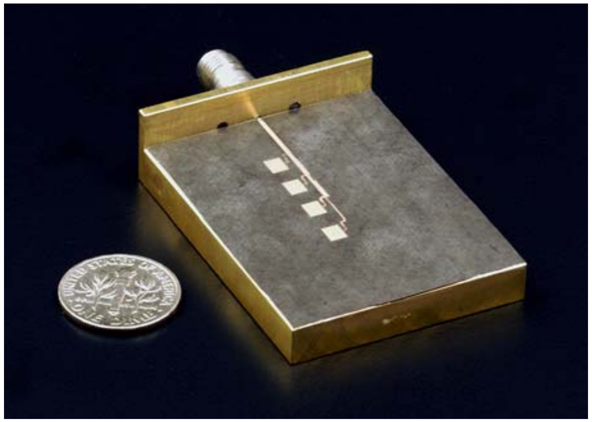
35-GHz feed array with H-pol and 30° scan:

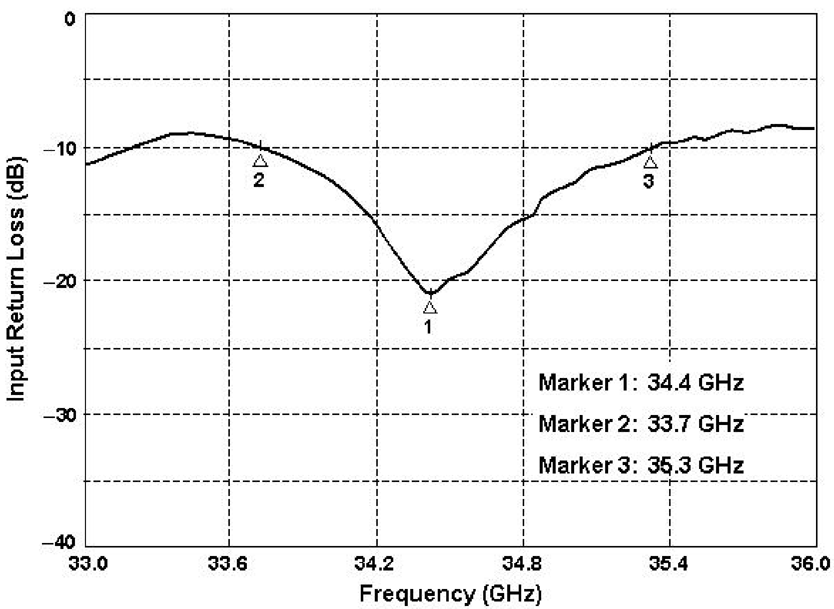
Each array has 4 x 166 microstrip patch elements
Size = 0.9m x 4cm
Substrate thickness = 0.25mm



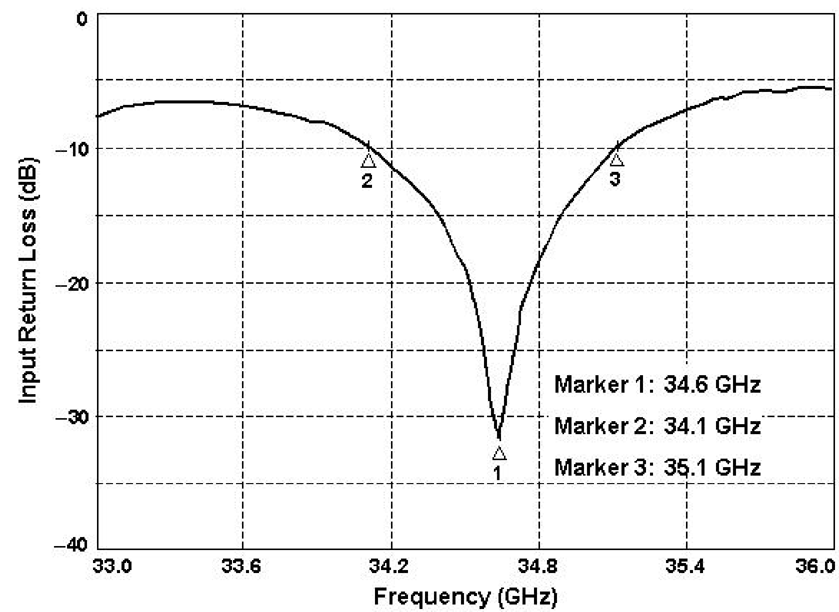
Fabricated Ka-band Subarrays and Test Results

H-Pol





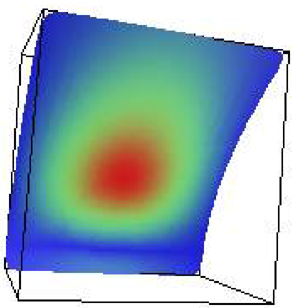
V-Pol



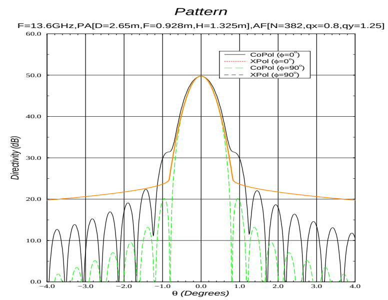
Ka-band Feed Array

Far-Field Patterns (Feeds are at Focus)

2x191 Cos^2 Feed [Ey =25 dB, dx=dy=0.63λ]

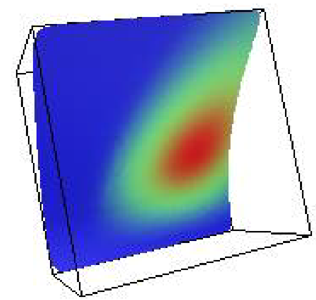


ϕ = 0˚
Directivity = 49.73 dB
HPBW = 0.66˚

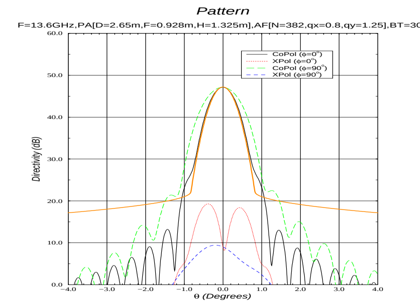


ϕ = 90˚
Directivity = 49.73 dB
HPBW = 0.6˚

2x191 Cos^2 Feed [Ey =25 dB, dx=dy=0.63λ] (BT=30˚)

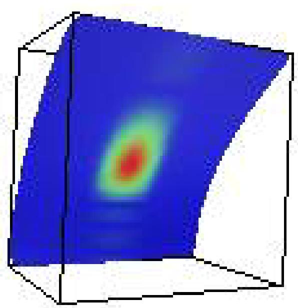


ϕ = 0˚
Directivity = 46.9 dB
HPBW = 0.6˚

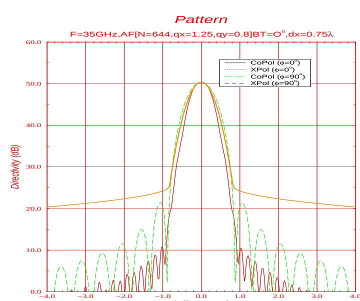


ϕ = 90˚
Directivity = 46.9 dB
HPBW = 0.72˚

4x166 Cos^2 Feed [Ey =22 dB, dx=0.75 λ,dy=0.63 λ]

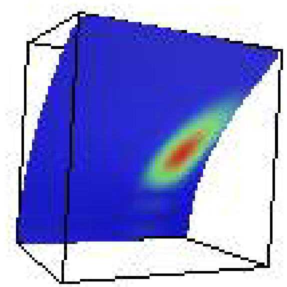


ϕ = 0˚
Directivity = 50.4 dB
HPBW = 0.52˚

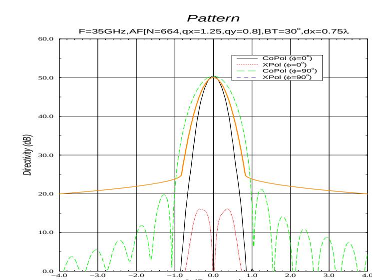


ϕ = 90˚
Directivity = 50.4 dB
HPBW = 0.66˚

4x166 Cos^2 [Ey =22 dB, dx=0.75 λ,dy=0.63 λ] (BT=30˚)



ϕ = 0˚
Directivity = 50.4 dB
HPBW = 0.44˚

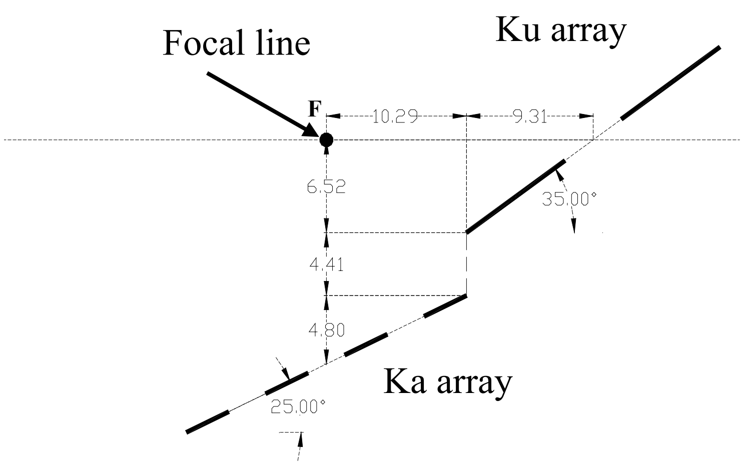


ϕ = 90˚
Directivity = 50.4 dB
HPBW = 0.78˚

In practice the Ku and Ka-band arrays cannot be simultaneously located at focus.

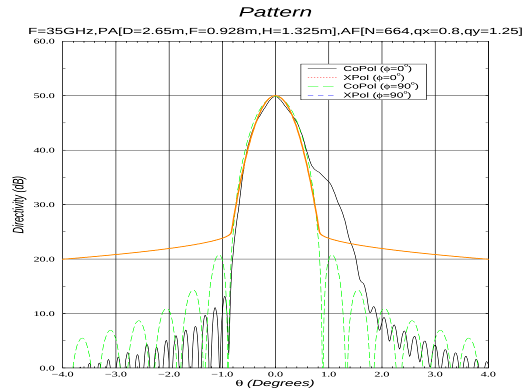
Proposed Feed Configurations: Option I

Both feeds are off the focal line

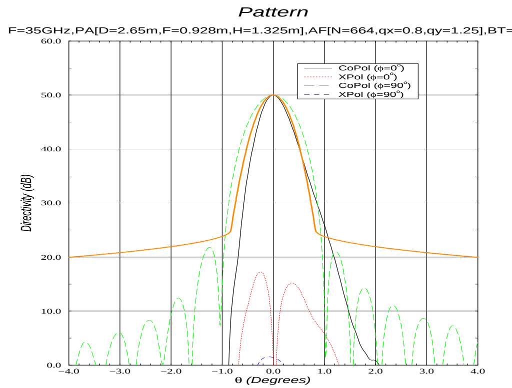


This configuration was proposed to avoid axial displacement at Ka-band.

Ka-band

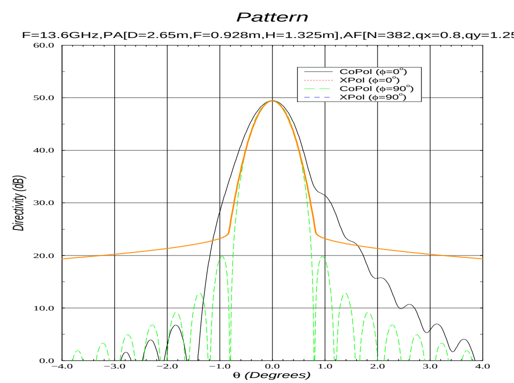


BT = 0°
Directivity = 49.8 dB
HPBW(ϕ=0) = 0.54°
HPBW(ϕ=90°) = 0.66°

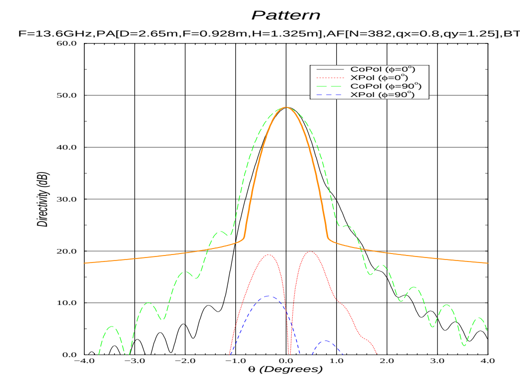


BT = 30°
Directivity = 49.4 dB
HPBW(ϕ=0) = 0.46°
HPBW(ϕ=90°) = 0.78°

Ku-band

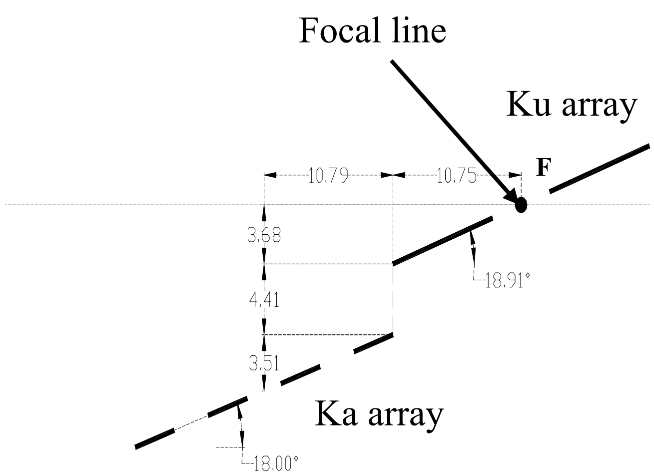


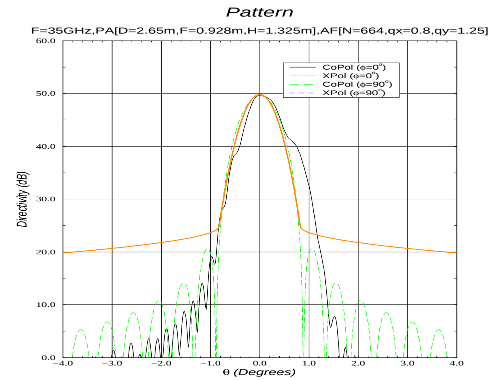
BT = 0°
Directivity = 49.8 dB
HPBW(ϕ=0) = 0.70°
HPBW(ϕ=90°) = 0.60°

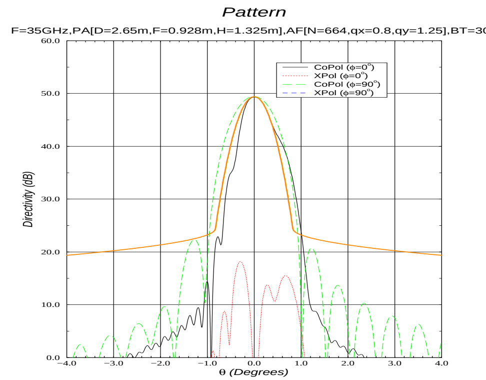


BT = 30°
Directivity = 47.6 dB
HPBW(ϕ=0) = 0.66°
HPBW(ϕ=90°) = 0.80°

Proposed Feed Configurations: Option II



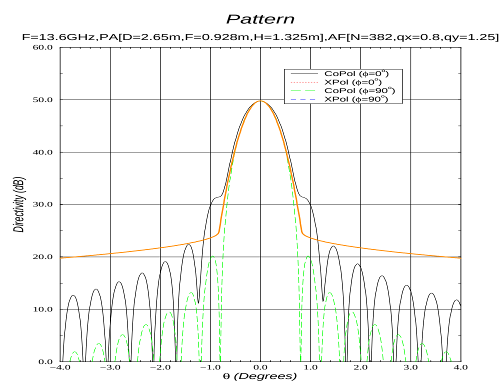


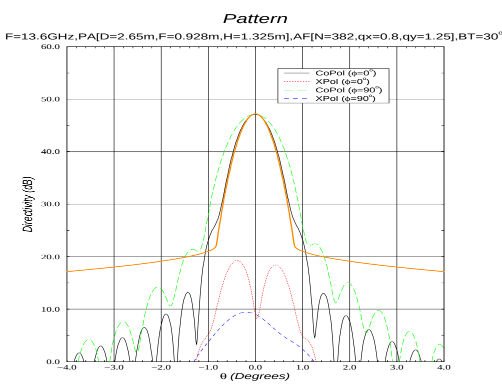


Ka

BT = 0°
Directivity = 49.6 dB
HPBW(ϕ=0) = 0.58°
HPBW(ϕ=90°) = 0.66°

BT = 30°
Directivity = 49.4 dB
HPBW(ϕ=0) = 0.52°
HPBW(ϕ=90°) = 0.76°





Ku

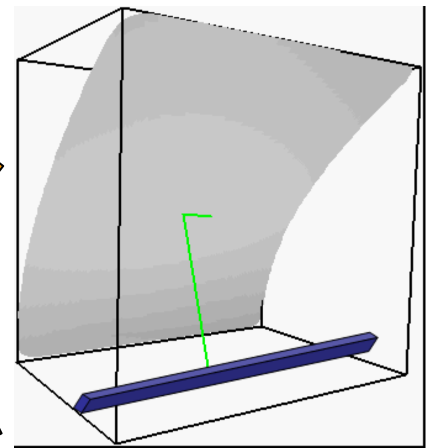
BT=0°
Directivity = 49.7 dB
HPBW(ϕ=0) = 0.66°
HPBW(ϕ=90°) = 0.60°

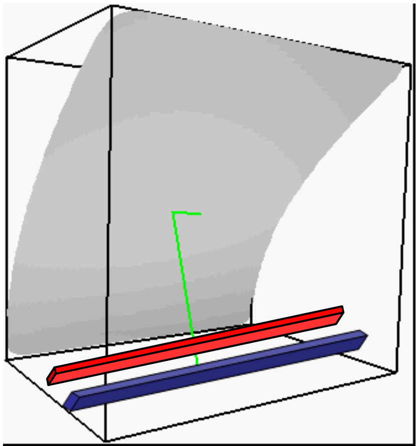
BT=30°
Directivity = 46.9 dB
HPBW(ϕ=0) = 0.60°
HPBW(ϕ=90°) = 0.72°

Ku-band feed is placed along the focal line and Ka-band feed is displaced.

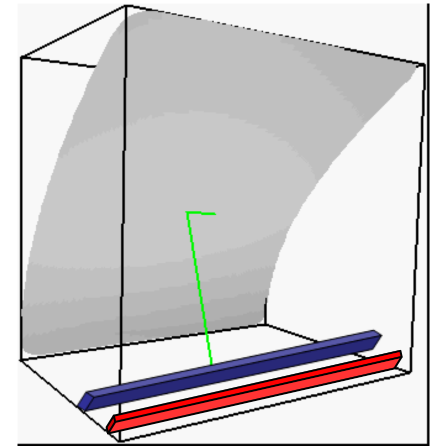
Feed Array Mechanical Tolerance Evaluations

Ideal feed

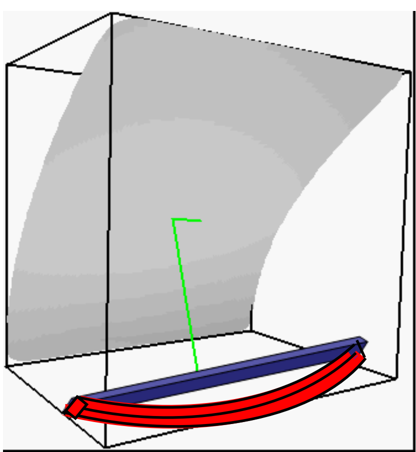




Lateral displaced feed



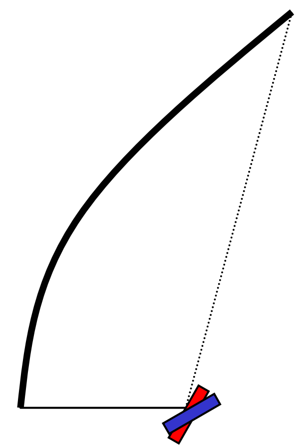
Axial displaced feed



Deformed feed

Objectives:

- Assess performance due to:
  - Gravity effect (in ground testing)
  - In-flight thermal distortion
  - In-flight dynamic distortion

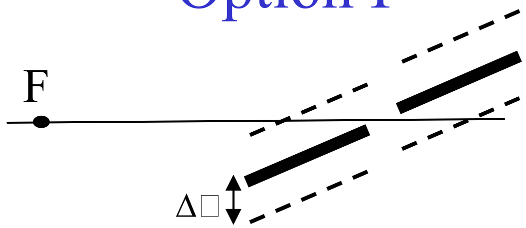


Rotated feed

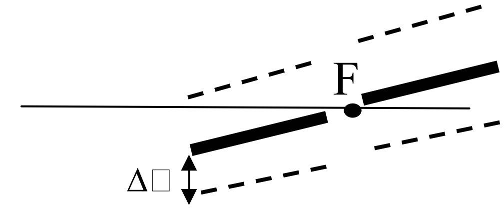
Ku-Band Lateral Feed Displacement (0˚ Scan)

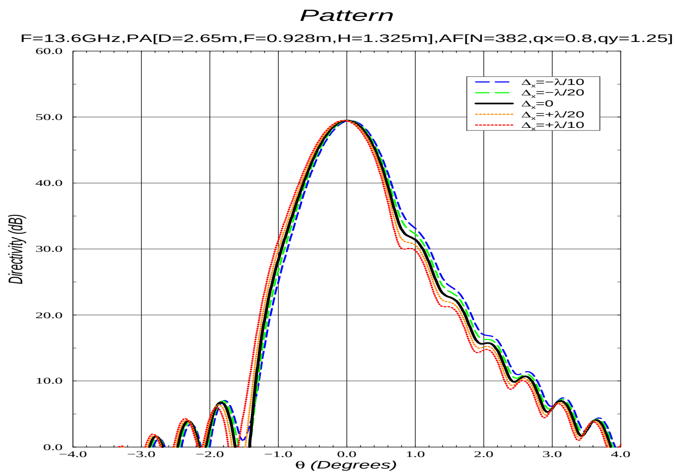
Ku-Band

Option I



Option II

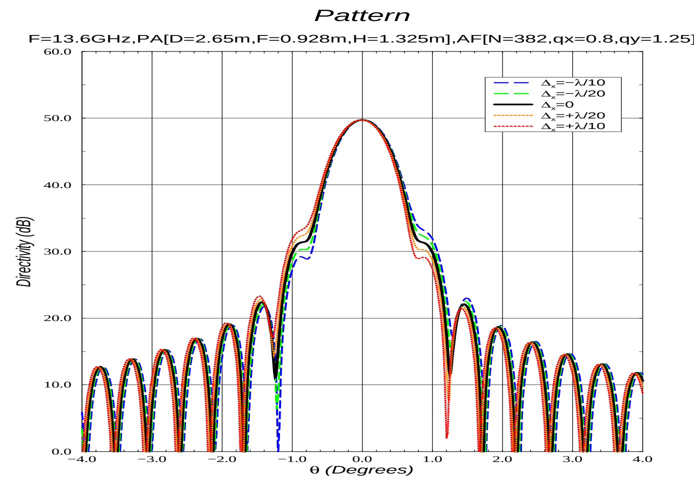




E-plane

Far Field Pattern

($\lambda = \lambda_u = 22$ mm)

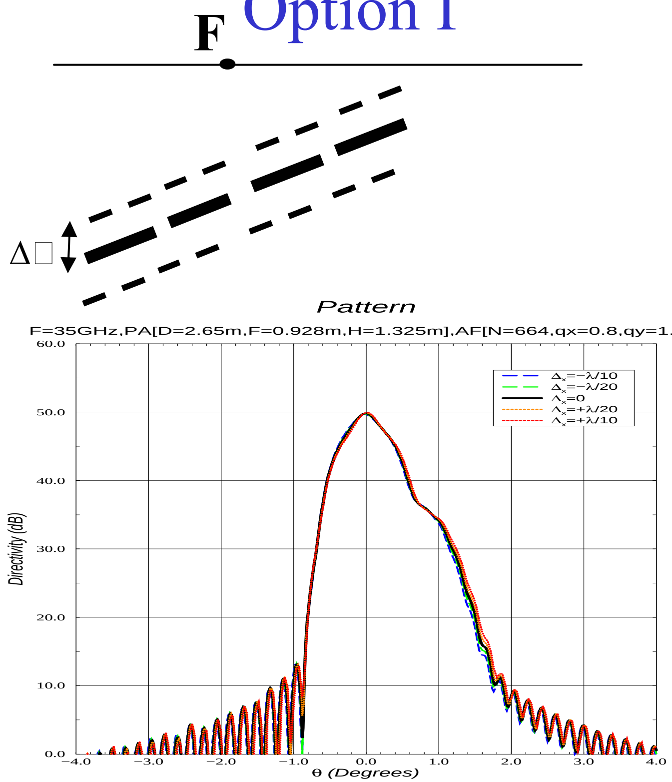


Beam Shift (deg)	λ/20	λ/10	λ/4	λ/2
Option I	0.02	0.06	0.12	0.24

Beam Shift (deg)	λ/20	λ/10	λ/4	λ/2
Option II	0.02	0.02	0.04	0.12

Ka-Band Lateral Feed Displacement (0° Scan)

Option I



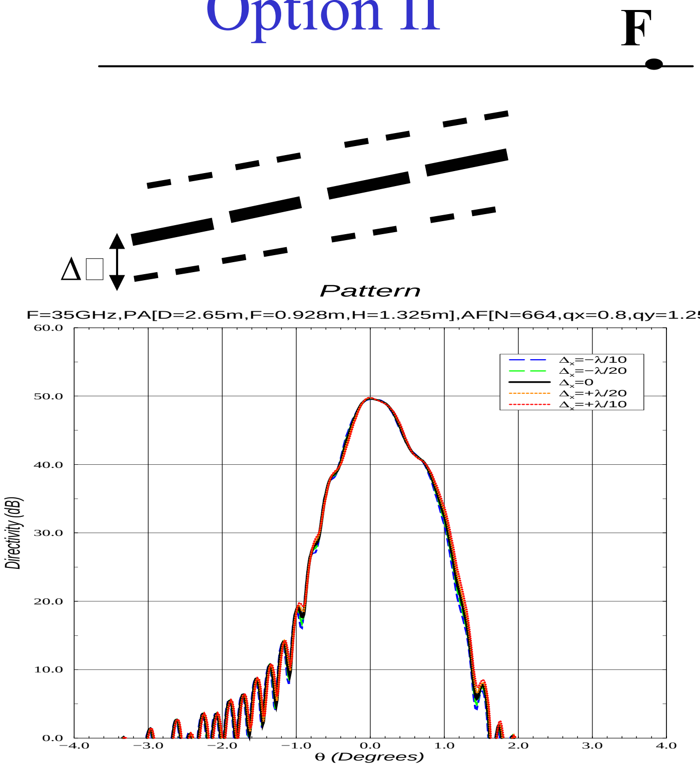
Ka-Band

E-plane

Far Field Pattern

($\lambda = \lambda_a =$ 8.5 mm)

Option II



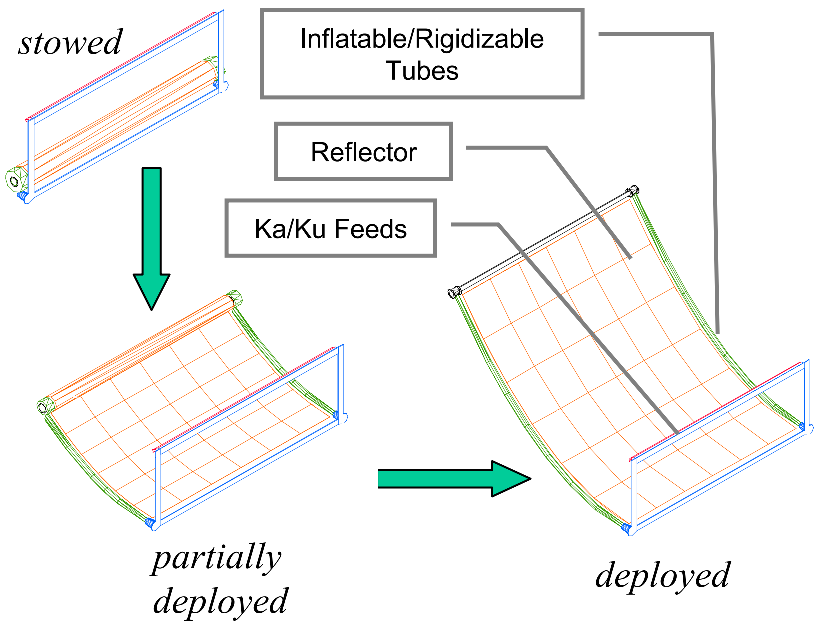
Beam Shift (deg)	λ/20	λ/10	λ/4	λ/2
Option I	0.02	0.02	0.04	0.08

Beam Shift (deg)	λ/20	λ/10	λ/4	λ/2
Option II	0.02	0.02	0.04	0.06

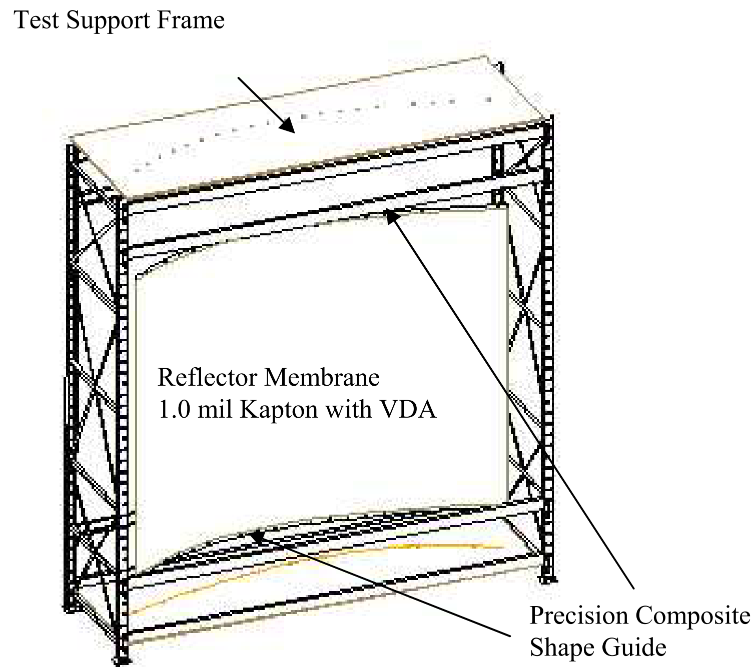
----> Result of comparison: Option II is preferred

APRA Mechanical Design

Design Concept



ILC Physical Model

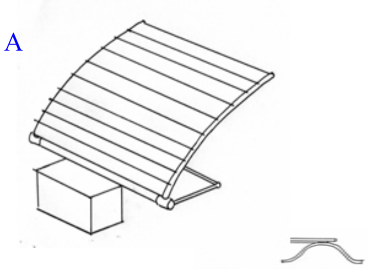


Mechanical Design Details

- APRA reflector must be deployable and must hold accuracy to the submillimeter level.
- Steps have been taken to find the best approach:
  - Various prototypes were evaluated for their ability to meet all the requirements
  - A space deployable "chain-link" support structure was chosen as the baseline design
- The antenna reflector is made of aluminized Kapton film in range of a few mils thickness and attached to the chain link support structure via an adjustable suspension system.
- In a spaceborne precipitation radar the film would be rolled up with the chain-link structure for launch and deployed following launch by deploying the chain-link structure.
- ILC will fabricate the half-scale prototype to demonstrate the above design
  - The feeds will be integrated and full pattern measurements will be conducted
- In addition JPL has developed a laboratory model for conducting studies on
  - The effects of film thickness
  - Gravity-induced distortion and sag
  - Film/structure interface and adjustable suspension
  - Level of tensioning
  - Feed support structure
- Studies are also being done to see how this type of structure performs in a zero-gravity environment using a model on the NASA KC-135 aircraft.

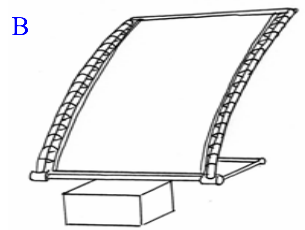
Prototype Design Concept Study

A



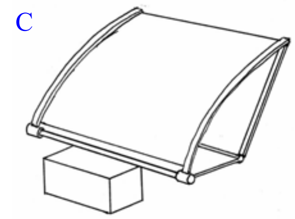
Formed U-Shaped Ribs

B



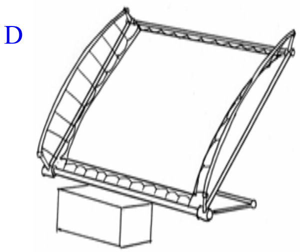
Formed Tubes

C



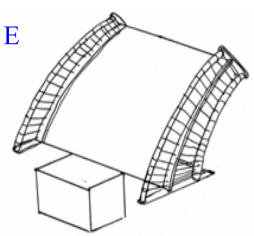
Shape Memory Strips

D



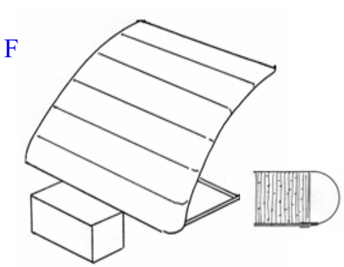
Bi-Axial Tensioning Catenary

E



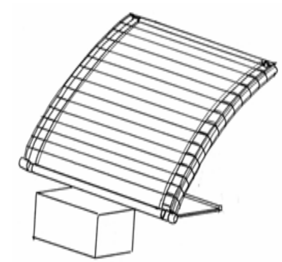
Radial String Support

F



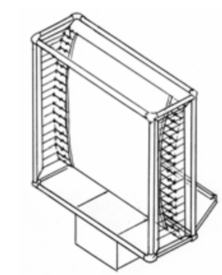
Drop-thread Inflatable

G



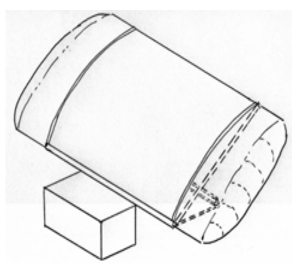
Hybrid Inflat. W/wrapped rib

H



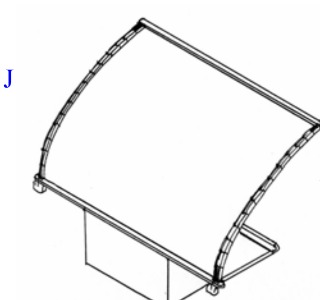
Chord Box w/Frame

I & K



Var. Thick. Inflatable Membrane

J

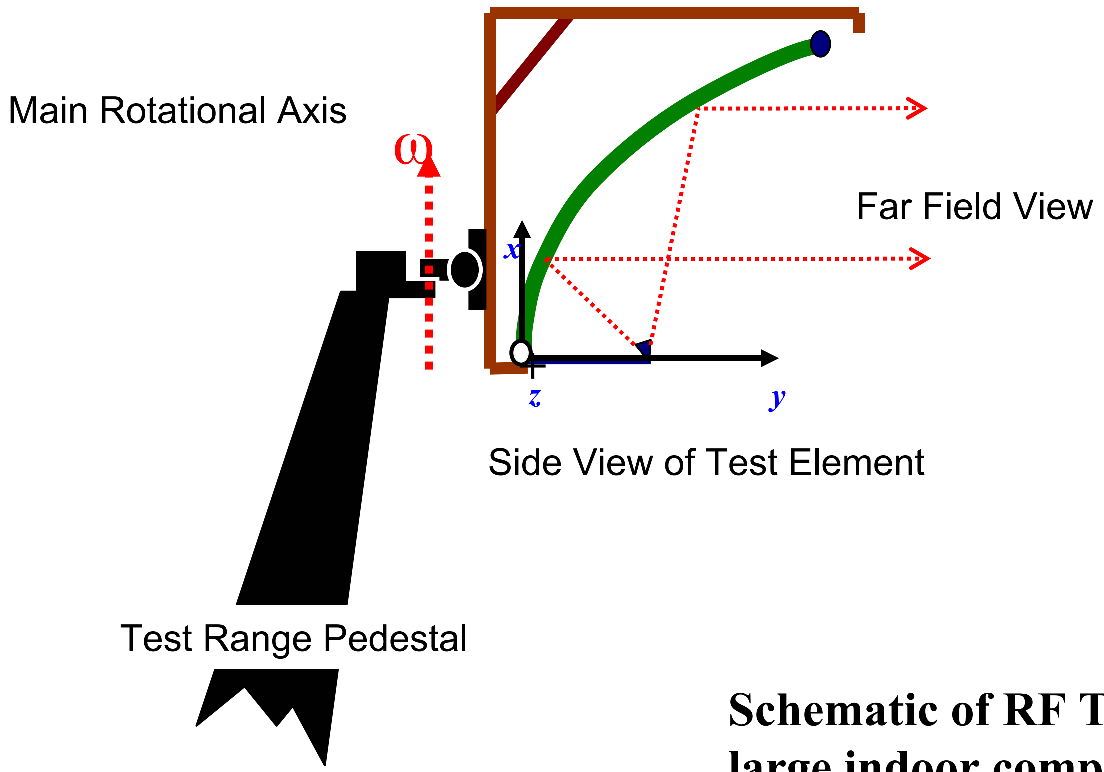


Selected for further development

Mech. Chain Support

RF Test Fixture Configuration

Most Relevant Antenna Test Setup



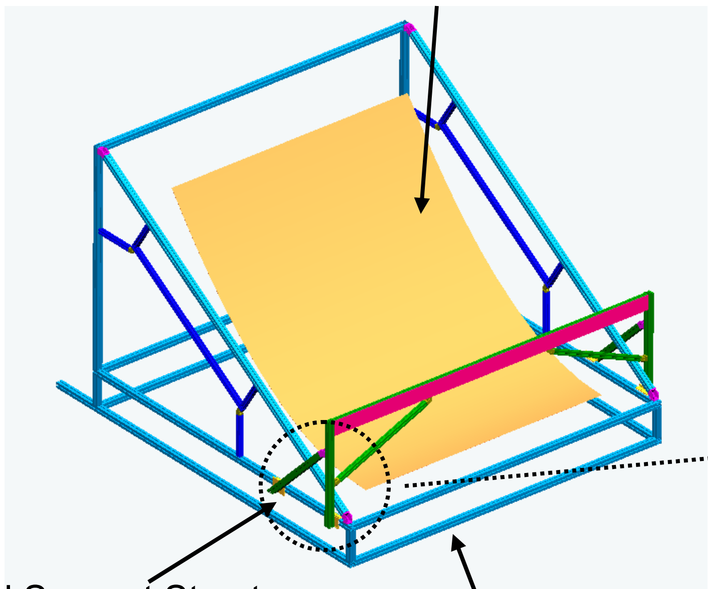
Schematic of RF Test Setup at COI large indoor compact range

Laser metrology will also be used to assess surface accuracy

Test Configuration Interface Defintion

Interfaces

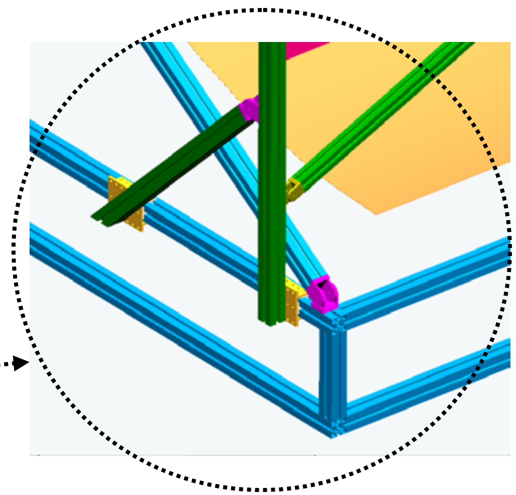
Reflector to Test Fixture

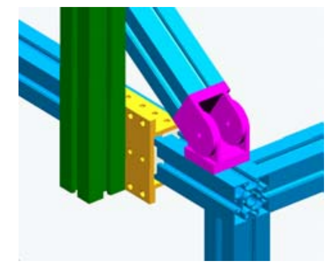


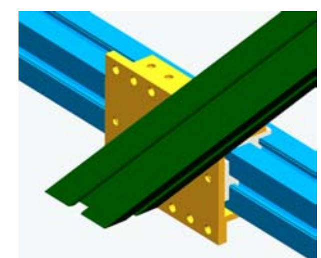
Feed Support Structure
To Test Fixture

Test Fixture to Test Range Pedestal

Details of Feed Support Structure to Test Fixture Interface

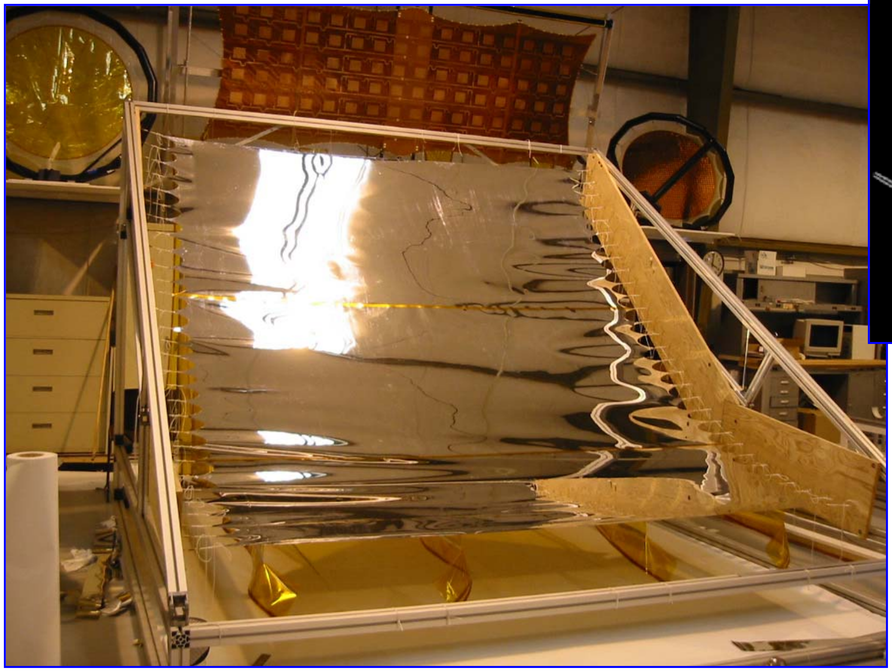


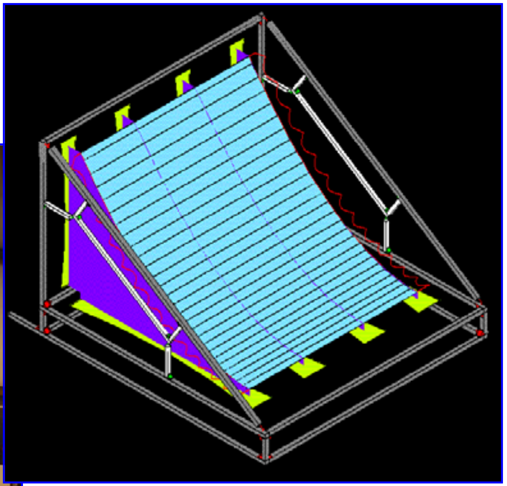


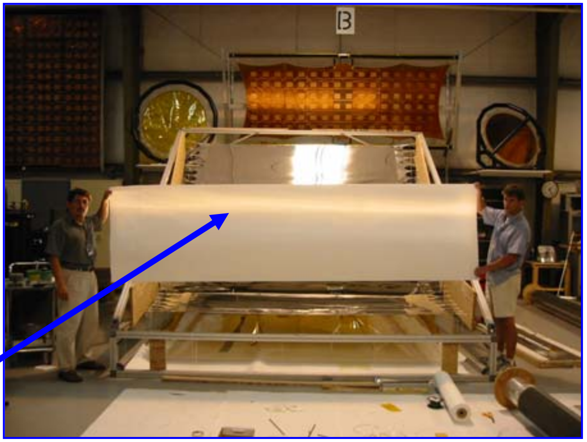


JPL Reflector Physical Model Manufacturing

View of the 2.65 m reflector suspended on the support bracket before final tuning. Inset drawing provided for comparison.

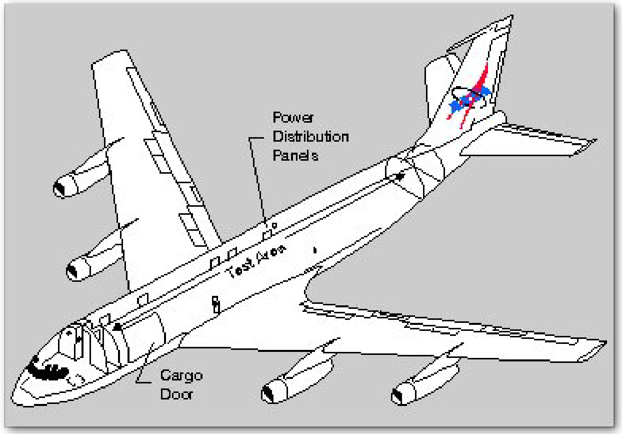


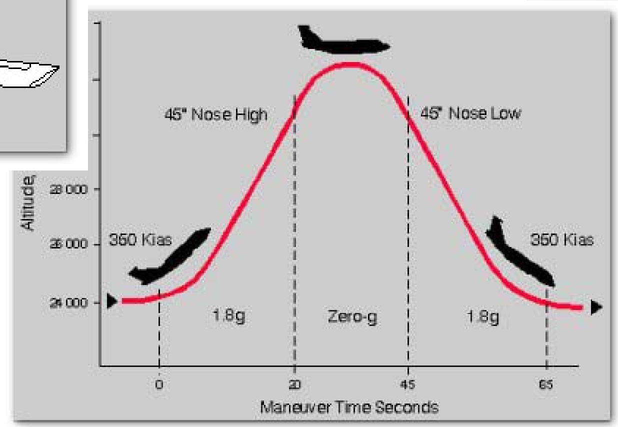




Notice bright line on paper as building lights are concentrated by the model reflector at the focal line.

Reduced Gravity Membrane Experiment





A subscale model of the APRA Reflector (1 m aperture) will be tested in the Reduced Gravity environment of the KC-135 platform. This experiment will explore shape profile of membrane under the reduced gravity vs.1-G environment and the phenomenon of ripple formation under reduced gravity (using optical metrology).

The experiment proposed by University of Kentucky, in collaboration with JPL and ILC Dover, has already been selected and will be flying in Summer of 2003. JPL will provide the mechanical test article.

Summary and Conclusions

- The 5.3 m deployable antenna design for PR-2 is being demonstrated by design, development, and testing of a half-size, 2.65 m, prototype model.
- The model's electrical performance has been characterized via electromagnetic modeling.
- Such modeling was used to derive the optimal feed locations and to understand the effects of feed displacements, needed for developing mechanical tolerances.
  - Results indicate that Ku-band feed should be on focal line
- An initial study evaluated a variety of mechanical deployment designs, with a chain-link support structure being selected.
- A 2.65 m reflector using this design is being fabricated and will be tested initially using laser metrology followed by repeated deployments, with additional laser metrology.
- In parallel, a set of fixed scan angle feeds is being developed for both frequencies, both polarizations, and both scan angles.
- Feeds and reflector will be integrated and tested early next year.
- Additional mechanical design studies are ongoing using a prototype built at JPL and also a second smaller prototype to be flown on the NASA KC-135 aircraft.